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An Integrated Scheme for Cyber-physical Building Energy Management System

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Abstract

Building energy management systems (BEMS) are gaining momentum as an alternative means to implement energy efficiency applications in large public buildings. A integration of Cyber-physical system and building energy management manifests an effective avenue for the pursuit of high energy efficiency. This paper presents a building energy management system with wireless sensor networks using multi-agent distributed control methodology that concentrates on optimized target of air-conditioning, lighting and official electrical devices. A tiered integrated approach provides multiple levels of sensing, processing, communication and management functionality. The paper also introduces a detail study of physical and cyber aspects of the system. The performance of the system and its application in a large campus building are shown finally.

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Keywords: Intelligent Building; BEMS; CPS; Multi-agent; WSN;

1. Introduction

An observation on energy consumption distribution shows that public and residential buildings represent more than 40% of the whole energy consumption in China, of which large scale public buildings account for about 60 % of the total[1]. As energy price goes high concomitantly with the needs of reducing dependence on fossil fuels usage and restricting carbon emissions, Energy consumption in buildings has

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been a bottle-neck problem that hinders sustainable development of economy in china. Therefore, it is an important aspect for building energy conservation that there should exist high efficient operating conditions for building equipments through optimized control schemes.

By observing large buildings, it demonstrates that a great number of technical possibilities for reducing the use of energy exist [2][3]. Building automation systems (BAS) are traditionally a widely accepted and adopted technology throughout buildings. Current building automation systems (BAS) encompass optimized control schemes for heating, ventilation, and air-conditioning (HVAC), lighting, and shading. And also it spans all application fields if they are composed of several independent subsystems. However, this integration is very challenging and mostly does not give the desired results to the users. The main open protocols now mostly used are BACnet, KNX, LonWorks and ZigBee that cover more than one application domain [3]. Usually processes in building automation system are executed automatically based on given parameters. BAS are deployed according to a hierarchical model analogous to the process automation pyramid with hierarchy layers are mostly separated. The traditional integration exhibits a tight integration of sensing, computation, and actuation within multiple physical domains.

A Cyber-physical building Energy Management System (CBEMS) presents an important avenue for the pursuit of high energy efficiency. A Cyber-Physical System (CPS) is the integration system between computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa [4]. A building energy management system is a computer-based integrated system which specifically focus on energy consumption monitoring and management. BEMS may present an ideal avenue for deploying CPS that emerges as an important instrument for boosting the overall efficiency in a large building.

This paper presents a building energy management system (BEMS) with wireless sensor networks using multi-agent distributed control methodology that concentrates on optimized target of air-conditioning, lighting and official electrical devices.

2. System architecture

The system is a tiered architecture, shown in figure 1, that comprises four layers, which are respectively, from bottom to top, field layer, Data acquisition and interface layer, automatic computing and executing layer, and management and monitoring layer. In the field layer, wireless sensor and actuator nodes interact with the physical world. These are computationally-simple low-duty cycle devices with few task-oriented objectives that operate as autonomous multi-agent systems that will be presented completely in the section 3. Data acquisition and interface layer comprises communication service models and middleware of sensors that communicate with personal agents through TCP/IP protocol. The middleware of sensors designed in API functions or component-based programming are responsible for gathering real-time data including thermal, electrical, occupants and environmental parameters and accessing them into RTDB(Real-Time database). It provides gateway functionality to upper level resources via **Ethernet network**. The automatic computing and executing layer are mapped to (i) intelligent computing modules and algorithms including abnormal condition alarming, policy learning ,result evaluation and Nash equilibrium approaches, etc.(ii) Database that are RTDB and Sql Server 2008 for storing historical data. The top layer goes to the energy management and monitoring layer that provides energy analysis or evaluation report, advices for energy-saving approaches, web services and human interfaces for the needed visualization such as monitoring flow chart, trending, value-setting, alarming, user authentication, data confidentiality and integrity, scheduling.

3. Cyber-Physical system for large public buildings

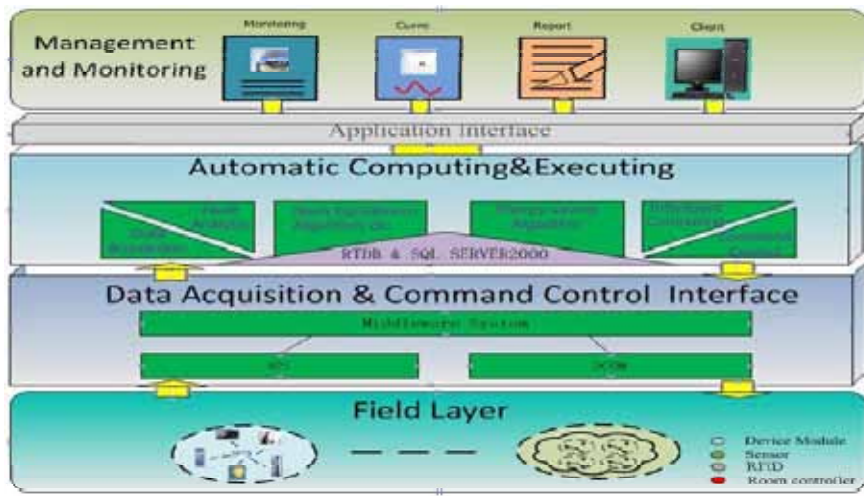


Fig. 1 System Architecture

3.1. Physical Aspects of CEBEMS—Based on a wireless sensor System

3.1.1 Building infrastructure

Form a energy efficiency analysis point of view, building infrastructure has three parameters zone of interests: electrical, heating, and occupant. The sensory devices presents here are temperature, humidity, switches, light intensity. It is possible to include other type of sensors such as presence of occupants, fire detectors, amps and voltages. Actuator devices includes switches, control valves, air-conditioners, or computers in offices. The RFID- based system makes it possible to know the presence of an occupant in a room or a location at any moment. Note that positioning here is typically used for triggering agent behavior which is not time-critical, at least not on a second-basis. The sensory devices provide input to the MAS and the actuator devices occasionally receive instructions from the MAS.

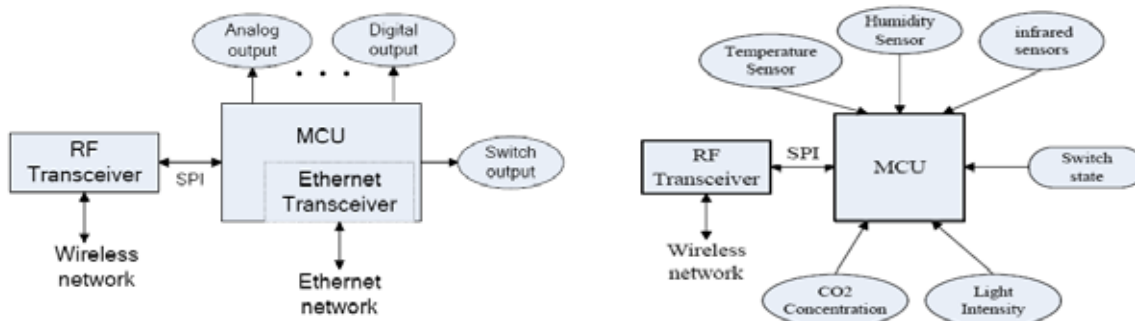


Fig. 2 Hardware Configuration Diagram. (a) Room Agent; (b) Environment Agent

3.1.2 Wireless sensor network system (WSNs)

The wireless sensor network system in our program that consists of wireless sensor nodes located throughout the physical environment are designed to be a durable, versatile platform for multi-agent

system cable of sensing(electrical, thermal, occupant parameters), actuation and communication. A hardware configuration, shown in figure 2, for a wireless sensor node is composed of a low power Micro-Controller Unit (AVR ATMEGA 64) with additional off-chip flash memory, advanced radio transceiver and connections for customized sensor/actuator. Some, if needed, also has an Ethernet interfaces for communication with upper level resources on the Internet.

3.2. Cyber Aspects of CEBEMS—Based on a Multi-agent System

CBEMS with a MAS approach presents highly advanced capabilities when dealing with large-scale distributed systems. MAS are aggregations of loosely coupled, networked agents, each with a set of inherent goals and limited purview to enable the implementation of scalable, flexible and distributed control systems. The MAS for building energy management emphasizes the dynamic configuration of building facilities to meet the requirement of building energy efficiency. The respective agents are: Personal Agent (PA), Environment Agent (EA), Room Agent (RA). A personal agent that is employed in a portable equipment with an embedded wireless radio frequency chip communicates with environment agents via wireless network. An occupant with identification number corresponding to a PA could be identified by environment agents when he comes into or out of the room. All local thermal, electrical and distributed environmental parameters, such as temperature, humidity, on/off of switches, occupants etc. are integrated by Environment Agents through wireless sensors, and sent to RA. Room Agent corresponding to a room or a location plays a central role in multi-agent system. Analyzing information received from EA through wireless network, RA sends accurate instructions to actuators and optimizes the status of all equipment in the room by self-learning and self-computing. All correspond parameters will be sent to upper layer of the system through Ethernet network..

4. Implementation

The Cyber-physical building Energy Management System (CBEMS) tested in a large campus building of Shandong Jianzhu university is a total integration of energy information system and cyber-physical system with wireless sensor networks using multi-agent distributed control schemes. It operates at a high level of intelligence and automation. Beyond accomplishing thermal and electrical inputs and outputs from legacy system, it actively reads versatile sensors of the building and subsequently control real-time data based on the cyber-physical system. It encompasses a set of specifically artifacts or subsystems and includes information exchanges between management objectives and field equipments.



Fig. 3. (a) A Client Interface; (b) Interface for monitoring HVAC system

The software structure of Monitoring and management subsystem is developed on Microsoft Visual Studio 2005.Net platform in C# language and has a three layer B/S paradigm of Browser/Web Server/Database. A client interface is shown in figure 3. For obtaining more flexible and more interactive applications that provides personalization, authentication, and aggregating content, several programming languages and components are also used. The system typically provides the following capabilities listed as the following:

- HTML/XML for designing web pages;
- Ajax for making a responsive web application, data-driven user interfaces and interactive animations on web pages;
- ActiveX Controls for rich data visualization and interactive charts;
- Real-time data Monitoring interfaces;
- Scheduling and intelligent Control: provides means to set parameters values;
- Trends and Reports: historical data statics and reports on one more I/O points;
- Security: for user authentication and integrity.
- Alarming Monitors: delivers alarms, keeps alarm logs, and waits for alarm acknowledgement.

5. Conclusion

Total integration of Cyber-physical system and building energy management introduces new opportunities and options for energy savings in large public buildings. The integrated scheme for CBEMS presented in the paper offers an ideal way for deploying CPS as an important instrument for boosting the overall efficiency of energy management in a large public building. The CBEMS has found its applications in a large public building of Shandong Jianzhu University, China. Initial results show the feasibility and high performance of the system.

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